IS 5542 (2003): Guide for Storm Analysis [WRD 1: Hydrometry]

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तूफान विश्लेषण की मार्गदर्शिका

(पहला पुनरीक्षण)

Indian Standard

GUIDE FOR STORM ANALYSIS

(First Revision)

ICS 93.160

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

May 2003 **Price Group 8**

Ground Water and Related Investigations Sectional Committee, WRD 3

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Ground Water and Related Investigations Sectional Committee had been approved by the Water Resources Division Council.

For any project concerned with irrigation, hydro-power, flood control and drainage, it is essential to have complete information on aerial and time distribution of rainfall over the concerned area or catchment. Data on other meteorological elements, such as wind, temperature, dew point, etc, are also useful in planning and execution of multipurpose river valley projects. This standard is intended to provide guidelines to engineers, project officials and various other agencies for hydrometerological analysis depending upon the nature of the project. This analysis is useful for flood studies, drainage design, spillway design, bridge waterways, etc. In the study concerning severe storms which occur in inaccessible areas, the regular observation networks may not provide enough information on rainfall distribution, therefore, weather radar instruments may be used to collect hydrological data. The data thus collected should be checked for their correctness and reliability after which the data should be statistically examined depending upon available resources and the importance of the project. For example, in cases of study of extensive well distributed storms, data from relatively less number of stations may suffice whereas in the case of intense storms of small extent, data from larger number of stations may be necessary. As it is only possible to outline the methods adopted for estimation, distribution and analysis of storms in a recommendatory manner the designer should exercise the discretion in analyzing the storm data pertaining to individual catchments.

This standard was first published in 1969. In this revision of the standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by driving assistance from the following publications:

a) Guide to Hydromet Practices (Vol-I) Data Acquisition and Processing, WMO No. 168 (1981),

b) Guide to Hydromet Practices (Vol-II) Analysis, Forcasting and Application, WMO No. 168 (1983), and

c) Manual for Estimation of Probable Maximum Precipitation. 2nd Edition. WMO No. 332 Geneva, 1986.

There is no ISO Standard on the subject.

The composition of the Committee responsible for the formulation of this standard is given at Annex D.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GUIDE FOR STORM ANALYSIS

(First Revision)

1 SCOPE

This standard lays down the guidelines for estimation, distribution and analysis of storm precipitation.

2 TERMINOLOGY

2.0 For the purpose of this standard the following definitions shall apply.

2.1 Isohyet — A line drawn on a map passing through places having equal amounts of rainfall recorded during the same period at these places (these lines are drawn after giving due consideration to the topography of the region).

2.2 Orographic Precipitation — Precipitation caused by moisture laden winds impinging on the rising slopes of hills and mountains. Precipitation is being caused by the cooling of the moist air consequent upon its being forced upwards.

2.3 Depth-Duration-Curve — The curve that shows relationship between duration and depth of precipitation of storm for a specified area.

2.4 Depth-Area-Duration-Curve — Set of curves on a single graph to depict maximum precipitation depths for various areas and duration in a particular rainstorm.

2.5 Dew Point — Temperature to which moist air should be cooled at constant pressure and with constant water vapour content in order to reach saturation with respect to water.

2.6 Storm — The term storm here implies to rainstorm commonly used for heavy rainfall over a region in association with some violent meterological phenomena like depressions/cyclones, etc.

2.7 Design Storm — Estimate of amount and distribution of rainfall over a given catchment, used in determining design flood.

2.8 Storm Depth — Average depth of precipitation over a specified area.

2.9 Storm Centre — The stations which records the maximum amount of rainfall during the storm period within the storm area.

2.10 Storm Efficiency — It is the ratio of the precipitated water over the storm area to the total precipitable water present in the atmosphere over the same area, during the storm period.

2.11 Envelope Curve — Smooth curve covering all peak values of rainfall plotted against area for a given duration time. In general, none of the peak values goes above the curve, called maximum envelope curve.

2.12 Moisture Adjustment — Adjustment of observed precipitation in a storm by use of ratio of estimated maximum precipitable water, over the catchment under study, to actual precipitable water, calculated for particular storm.

2.13 Storm Duration — It is the period (hours/days) for which the storm of particular intensity persists.

2.14 Return Period — Statistical parameter used in frequency analysis as measure of most probable time interval between occurrence of a given event and that of an equal or greater event.

2.15 Meteorological Homogeneity — A region is said to be meteorologically homogeneous if the stations therein have very nearly the same rainfall frequency distribution and type of storms.

2.16 Mass Curve — Curve in which the values of cumulative rainfall are plotted against time.

2.17 Precipitable Water — Total amount of water in vapour form in the vertical column of air of unit horizontal cross-section.

2.18 Storm Transposition — The application of a storm pattern over one area to some other area within the same region of meterological homogeneity. Due regard should be given to climatological factors like seasonal storm tracks, etc, in deciding the orientation of the storm over the transposed area.

2.19 Point Rainfall — Rainfall recorded at a raingauge station for a specified duration.

2.20 Isopleths — A line representing equal or constant value of a given parameter on a map or chart.

2.21 Moisture Maximum Ratio — It is the ratio of highest liquid water content in atmosphere on record during storm season to the actual liquid water content present during the storm time.

2.22 Areal Rainfall — Average rainfall depth observed or estimated over an area.

3 RELIABILITY OF OBSERVATIONAL DATA

3.1 Before the storm precipitation data collected are

used for study and analysis, their reliability shall first be ascertained.

Preliminary checking shall include the following to find out if:

a) period of record has been continuous;
b) observatory was not shifted during the period;
c) completeness and correctness of indicative information is ensured, the dates and name of the stations are correctly indicated in the report;
d) correctness of the data regarding totalling, calculation of averages, etc, are checked; and
e) comparison with adjacent stations of similar elevation if any, under the influence of the same rain storm is made.

4 DETERMINATION OF AVERAGE DEPTH OF PRECIPITATION OVER AN AREA

4.1 Since most hydrological problems require knowledge of the average depth of rainfall over significant area, such as a river basin, the method given in **4.2** to **4.5** may be adopted to convert the raingauge measurements to aerial averages.

4.2 Arithmetic Mean Method

The arithmetic mean of the systematic rainfall measurements made at all the raingauge stations within the area shall be calculated. If the raingauges are distributed uniformly and if the variations of individual gauge catches from the mean is not large, this procedure fairly accurate results. This method is suitable for basin gives with large number of rain gauge stations spaced uniformly. Even in mountaineous catchments, arithmetic averages will yield fairly accurate results if the orographic influences on precipitation are considered in the selection of raingauge sites. Sporadic high rainfall depth not supported by information from other stations has to be discarded discretionally to ensure that it is not due to the influences of steep valleys or hills.

4.2.1 *Limitation*

This method is likely to lead to considerable error in estimates if the raingauge net work over the catchment is non-uniform and sparse and the catchment is highly orographic.

4.3 Thiessen Polygon Method

This method is used for non-uniform raingauge net work by assigning weights to station data in proportion to the space between the raingauge stations. A Thiessen network (*see* Fig. 1) shall be constructed by locating the raingauge stations on a map and drawing the perpendicular bisectors to the lines connecting the stations. The polygon thus formed around each station is the boundary of the effective area assumed to be controlled by the station, that is, the area which is closer to the station than to any other station.

The area governed by each station is planimetered and expressed as percentage of the whole area. The average depth of precipitation for the entire basin is calculated by the following formula:

$$P = \frac{\sum_{r=1}^{n} P_r A_r}{\sum_{r=1}^{n} A_r}$$

where

P = average depth of precipitation for the entire basin;

$P_1, P_2, P_3, \ldots P_r \ldots P_n$ represent the readings at the raingauge stations in the basin;

A = area of the entire basin, that is:

$$A = \sum_{r=1}^{n} A_r$$

$A_1, A_2, A_3, \ldots A_r \ldots A_n$ represent the areas surrounding the raingauge stations whose readings are P_1, P_2, $P_3, \ldots P_r \ldots P_n$ respectively.

4.3.1 The advantage of this method over the arithmetic mean method is that the data of stations outside a catchment may be used for assigning weights to stations influencing peripherical areas of the catchment.

4.3.2 *Limitation*

This method does not take into account the orographic features and also every time the network of stations is changed, the Theissen Polygons are to be drawn again.

4.4 Isohyetal Method

The isohyetal map is constructed by plotting the precipitation amounts for each station on a suitable map and then drawing lines of equal precipitation (isohyets) at proper interval. If the shape of the isohyetal pattern is not definitely known the isohyets may be interpolated between stations. In drawing the isohyets, care should not only be given to each individual rainfall plot, but also to the orographic feature (*see* **4.4.1**). The average depth of precipitation for the basin shall be determined by computing the incremental volume between each pair of isohyets, adding these incremental amounts and dividing by the total area as given in the following formula:

$$P = \frac{\sum_{r=1}^{n} P_r A_r}{\sum_{r=1}^{n} A_r}$$

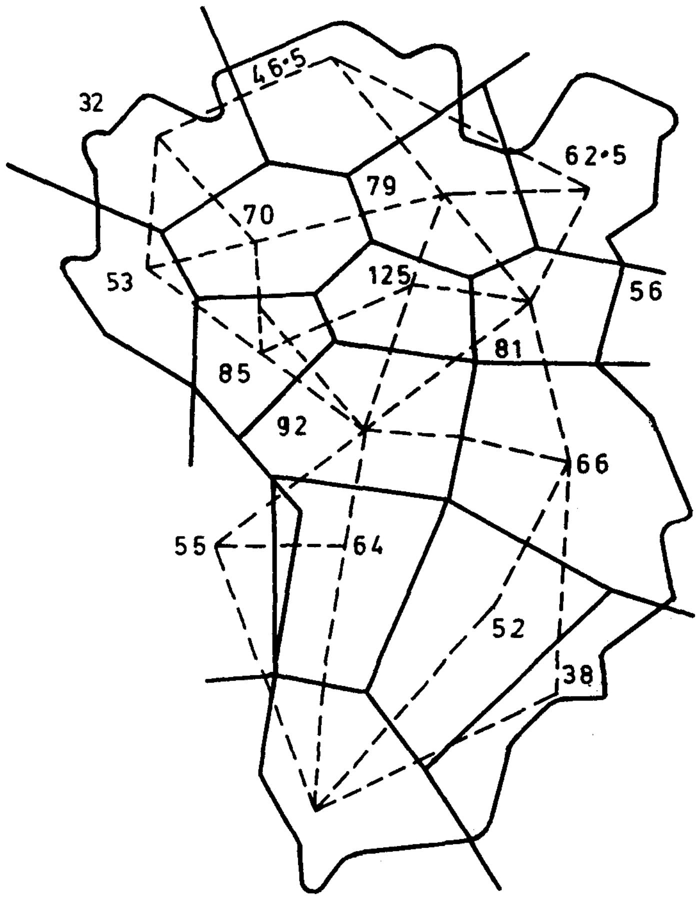

FIG. 1 THIESSEN NETWORK (AVERAGE PRECIPITATION = 63.5 mm)

where

P = average depth of precipitation for the entire basin of area A, that is,

$$A = \sum_{r=1}^{n} A_r$$

$A_1, A_2, A_3, \ldots A_r \ldots A_n$ are the areas between successive isohyets measured by the use of a planimeter; and

$P_1, P_2, P_3, \ldots P_r \ldots P_n$ represent the average rainfall on the areas $A_1, A_2, A_3, \ldots A_r \ldots A_n$ respectively (usually taken as one half the sum of the two consecutive isohyets).

4.4.1 Since this method is likely to give rise to subjective errors and as the orographic features have to be taken care of, the isohyets may roughly follow the actual ground contours or the isohyets of seasonal precipitation. Orographic precipitation generally increases with altitude upto a certain height.

4.5 Percent Normal Method

In mountaineous regions, mean annual and mean seasonal precipitation maps may be constructed taking into account the average effect of physiography on precipitation. In this method storm precipitation is expressed as a percentage of mean annual or mean seasonal precipitation and iso-percental maps are used for preparing isohyetal maps. This method may have to be adopted for storm study in regions of pronounced physiographic influence from where data pertaining to storm under study may be either scanty or missing.

5 STORM ANALYSIS

5.1 Selection of Storms

A judicious selection of a few storms which are representative for the whole catchment shall be made for study as considering a large number of storms for analysis would be uneconomical and time consuming leading to results not better than those which a few important storms would indicate. In order to make a realistic assessment of storms, complete information regarding the area and location of the catchment, rainfall regime and seasonal rainfall should be collected. Initially, the data connected with the most

recent storm should be considered to determine a criterion for the selection of storms. For example, a plot of the point rainfall either as storm total (that is sum of the precipitation during the period of storm) or the sum of precipitation for an individual day which appears by inspection to be the rainiest connected with that particular storm would indicate in general the position of storm centres in the catchment under consideration. The selection of storms for detailed analysis should be made by fixing threshold value, the occurrence of which would justify the storm selection.

5.1.1 The selection of the threshold value will, however, depend upon the extent of the storm as well as the depth of precipitation at the storm centre. The following criteria would serve as general guide for fixing the threshold values for storms.

a) So far as the aerial distribution is concerned the occurrence of 50 mm of precipitation per day over a catchment of medium size (at least it covers the project catchment area) would be a fair criterion.
b) Where a storm has to be selected on the basis of the central rainfall as manifest from the total precipitation of a station or stations it has to be ensured that the extent of the storm is not small (say not less than 10 000 km^2) with rainfall at the peripheral isohyet being of the order of 25 mm. This will, however, be subject to climatological features of storm of the region. For example, in arid and semi-arid regions with low seasonal rainfall, the last isohyet may be of the order of 10 mm, while in region of high rainfall it may be higher than 25 mm.

5.2 Storm Study Techniques

In order to obtain quantitative estimate of design storm for any basin, comprehensive analysis of major rainstorms that had occurred in and near the basin shall be undertaken. The following three methods may be used for design storm study:

a) Depth duration analysis,
b) Depth duration area analysis, and
c) Storm transposition technique.

5.2.1 *Depth Duration Analysis*

The relationship between time and depth of precipitation may be obtained by the depth duration curves which are constructed by plotting the depth of precipitation against time. In this method the catchment shall be taken as the unit of study and for each rain spell separate isohyetal maps are prepared. Each map shall be planimetered and the average depths of rainfall over the catchment shall be obtained for all the days of the rain spell. These depth values are then plotted against duration to obtain depth duration curves for each rain spell.

5.2.2 *Depth Duration Area Analysis*

The object of depth duration area analysis of a particular rain storm is to determine the highest average depth of precipitation over different areas around a storm centre during standard durations of hours or days. Generally, the storm is assigned a duration from a period of no rain to the next period of no rain. This ensures that storm totals from all stations are for exactly the same time interval or for the period of principal burst.

5.2.2.1 In this method the rain storm shall be taken as the unit of study and any major rainspell whose heavy rainfall centre was located in and near the catchment, could be selected for depth-duration-area analysis. To arrive at the depth-duration-area curve, the following steps should be followed:

a) Depth of point rainfall for one day, two day, three day, etc, for each station shall be obtained. Care should be taken to determine the rainiest day for most stations as the first day. The subsequent two days is selected by adding the depth of first day with the second preceding or following most rainiest day's values. Similar technique is adopted for three days or higher duration rainstorms.
b) The depths of precipitation shall be plotted on separate suitable base maps preferably 1 : 1 millions scale of the region showing raingauge stations, height contours, etc, and isohyetal lines are drawn. The area enclosed within the isohyetal lines shall be measured by a planimeter and multiplied by the mean isohyetal values to compute precipitation depth. The computed depth values and the corresponding areas shall be plotted to form the depth duration area curves for each rain storm for various durations. From these curves envelope curves intended to cover practically all observed rainfalls are obtained. The maximum depth duration area data for each area of 100, 500, 1 000, 5 000, 10 000, 25 000, 50 000, 100 000 km^2 around the storm centres and at durations of 6, 12, 18, 24, 48, 72 h may then be obtained from the curves so drawn. For more accuracy in reading depths for smaller areas, curves upto 5 000 km^2 on a larger scale may be plotted.

5.2.2.2 The isohyetal maps (*see* Fig. 2, 3 and 4), computational sheets (Annex A) and the depth duration area curves (*see* Fig. 5) for a typical storm on a typical catchment for the period of 27 to 29 July 1965 is given

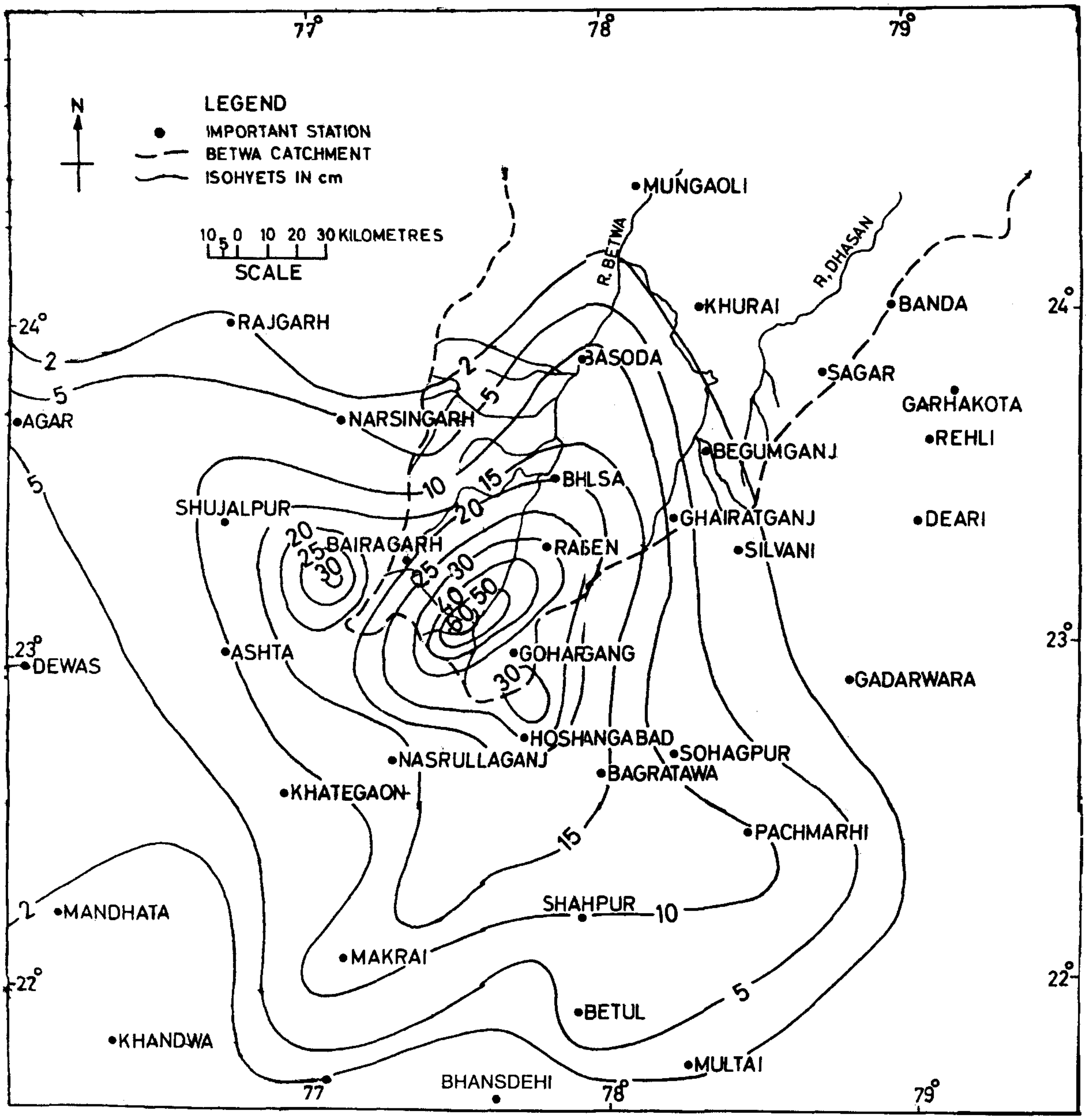

FIG. 2 TYPICAL ONE DAY ISOHYETAL PATTERN OF RAINSTORM OF 28 JULY 1965

as an example. The maximum 1 to 3 days depth of rainfall over required areas are picked up from the depth-duration-area curves (*see* Fig. 5).

5.2.2.3 Depth-duration-area data are valuable as they give, for a storm, the maximum rainfall depths for a given duration averaged over areas measured outwards from the centres of heaviest rainfall.

5.2.2.4 Depending on the use to which the storm analysis is to be put, care should be exercized in combining precipitation data from the zones where topographical and meteorological influences are not comparable. For example, taking an average of precipitation over a mountaineous range and adjacent plains will be misleading. Similarly, precipitation in two widely separated centres may be the result of unassociated meteorological causes.

5.2.2.5 In general the depth-duration analysis would give the storm distribution characteristics of the catchment in question, while depth-duration-area analysis will ensure the possibility of occurence of the severest neighbouring storm over the catchment in question is taken care of (through storm transposition).

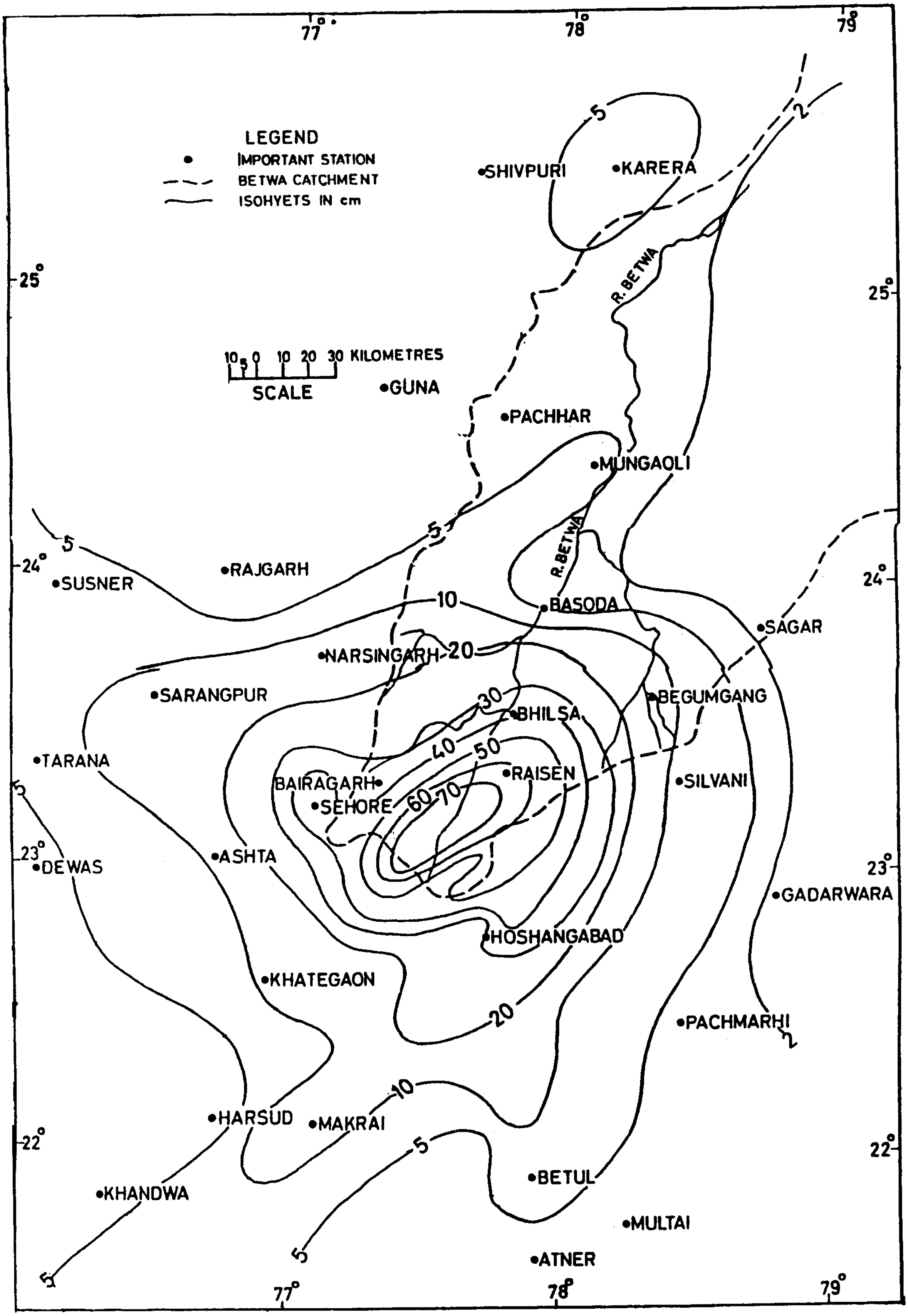

FIG. 3 TYPICAL TWO DAYS ISOHYETAL PATTERN FOR RAINSTORM OF 28-29 JULY 1965

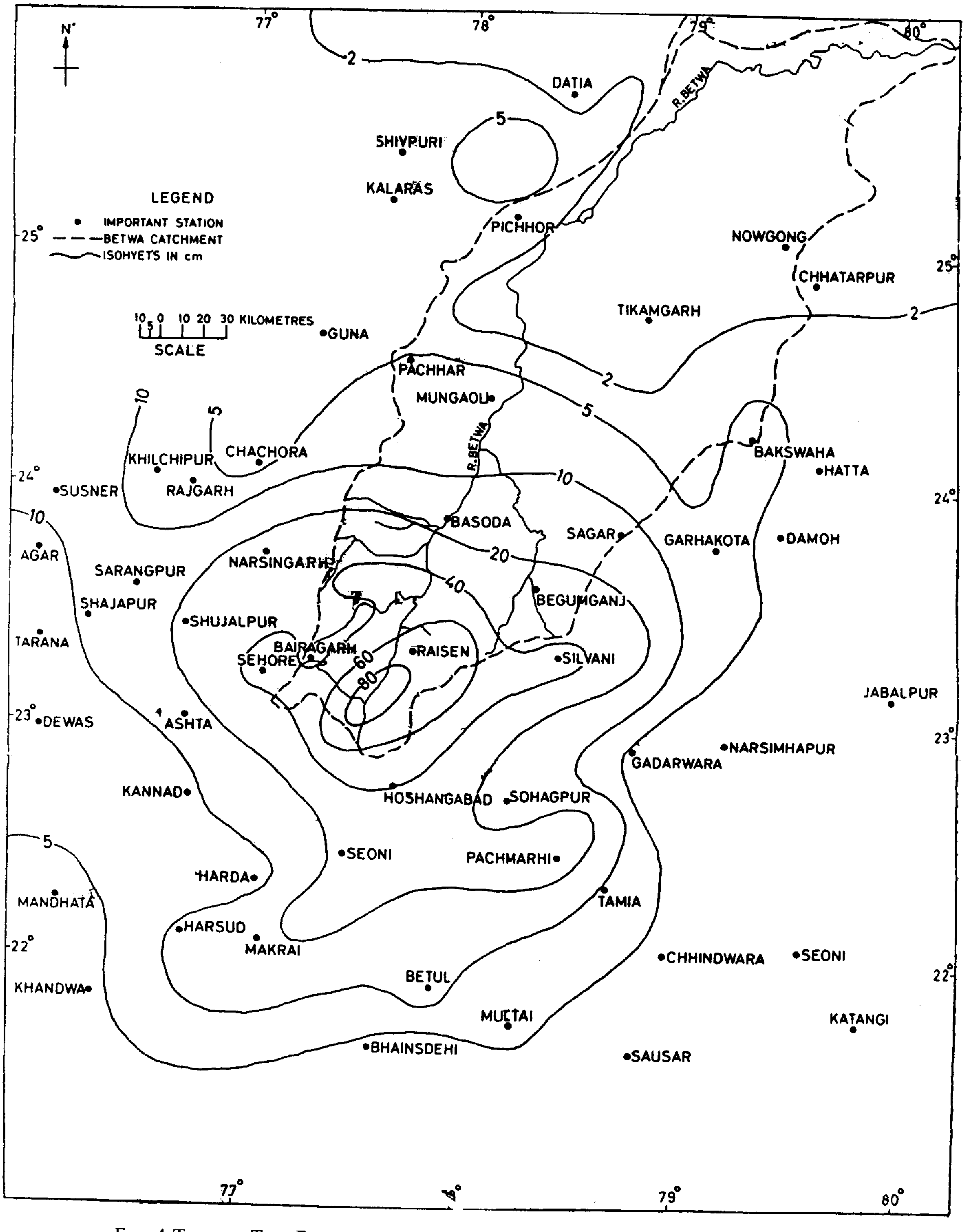

FIG. 4 TYPICAL TWO DAYS ISOHYETAL PATTERN FOR RAINSTORM OF 27-29 JULY 1965

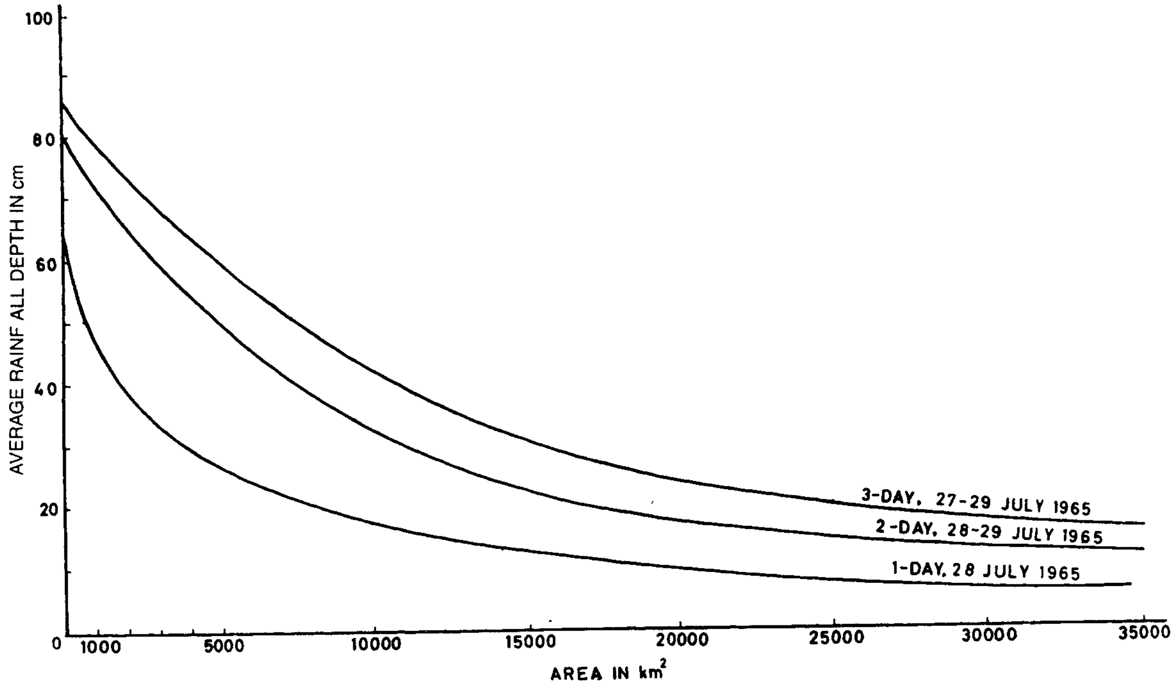

FIG. 5 TYPICAL DEPTH DURATION AREA CURVES

5.3 Storm Transposition

It means the application of a rainstorm from one area to another area within the same region of meteorological homogeneity. It only requires to be ensured that a particular rainstorm could have occurred in the area to which it is to be transposed.

5.3.1 The purpose of storm transposition is to increase the storm experience of a basin by considering not only rainstorm which have occurred over that watershed, but also those which released their heaviest rainfall on meteorologically homogenous areas. While bodily transposing the rainstorm, due regard should be given to the orientation of the rain storm with respect to the basin. The rainstorm of mountaineous regions cannot be transposed as the magnitude and aerial distribution of precipitation are conditioned by the topography and no method is fully satisfactory to ensure the required adjustments for topography. The storm transposition limits are based on a knowledge of atmospheric processes, the climatological features and orography.

5.3.2 *Steps in Storm Transposition*

Some of the important steps in storm transposition are given below:

a) *Delineation of storm rainfall* — The first step in transposing a storm is to identify its centre, that is, where and, when the heaviest rain in the storm area fell. An isohyetal map is useful for this purpose. The study of isohyetal maps reveals that in general the heavy storms are elongated in shape in so far as the rainfall distribution is concerned. The major axis passing through the storm centre is considered as the axis for storm transposition. A knowledge of most commonly observed orientation of storm rainfall pattern on the project basin is also helpful in determining the layout of the transposed storm on this catchment for maximum rainfall run-off studies. Care should be taken to see that the major axis of the actual storm is not tilted beyond 20° while transposing to a project basin (*see* Fig. 6).

b) *Causes of storm rainfall* — The second step is to identify usual synoptic situation causing the storms. It may be traced in upper air circulation if not identified on the surface weather charts. In order to get an insight into the storm producing potential a study of usual synoptic situations affecting the project basins by a meteorologist is essential.

c) *Region of influence* — The third step is to mark the areas most susceptible to storm occurrences of particular intensity. This is required to find the least time lapsed between mid period of storm and peak discharge and may be accomplished by a study of a series

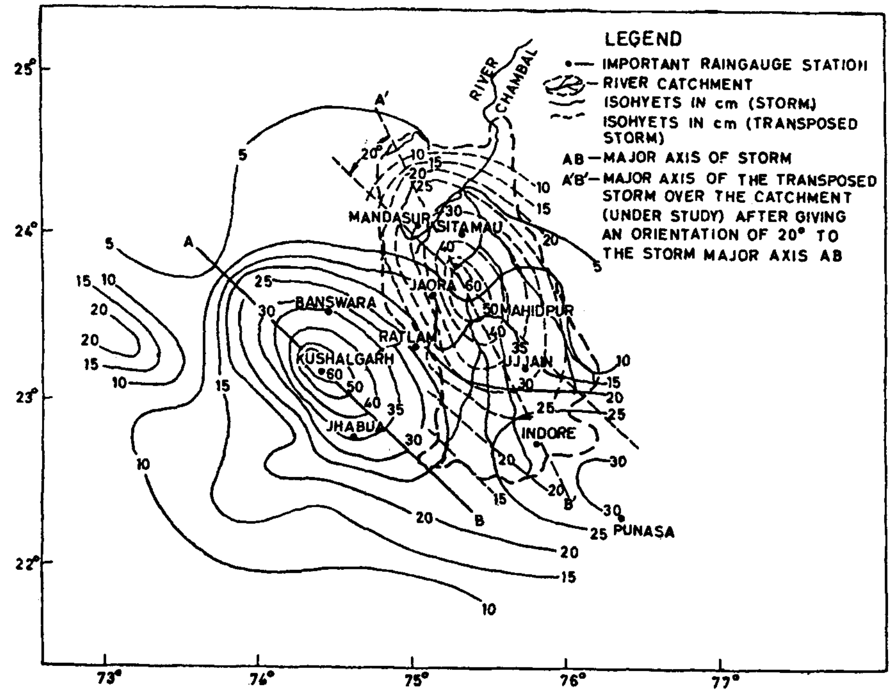

FIG. 6 STORM OF 26-27 JULY 1913 TRANSPOSED OVER TYPICAL CATCHMENT (ISOHYETS IN cm)

of past heavy storms with reference to their tracks.

d) *Effect of topography* — The fourth and the most important step is that while marking the boundary of the region over which a storm may be transposed with some minor modifications the effect of topography, the nature of underlying surface, and local influences, such as mountains on rainfall distribution should be taken into account. For example, in mountaineous regions the rainfall pattern is largely fixed by topography and, therefore, the patterns are best defined by the major storms of the immediate area. Again the coastal rainfall is not transposed far inland area.

e) *Storm adjustments* — Having considered the factors causing a storm, the following adjustments, such as those for moisture, topography and season have to be incorporated before transposition is actually carried out:

1) *Moisture adjustment* — Areas near the coast are more damp than those inland and the moisture parameter varies from region to region and from season to season. To bring about the adjustment the ratio of two precipitable waters from surface to some great height (say 200 mb, level) at the position of the storm and at its transposed location, shall be found. The dew points at the two positions may be used to calculate the depth of the precipitable water (*see* Note). The ratio of the two precipitable water is the moisture adjustment ratio, and will be greater or less than unity depending on whether the transposition is towards or away from the source of moisture. The depth duration values for all storms should be multilplied by this ratio. In case when the storm is both maximized for moisture and transposed with moisture adjustment, a single adjustment ratio may be used.

Moisture maximum ratio × Transposition adjustment for moisture

$$= \frac{\text{Maximum precipitable water at new location}}{\text{Storm precipitable water}}$$

NOTE — Charts showing mean monthly precipitable water are available with the India Meteorological Department for reference.

2) *Topographical adjustment* — Regions of steep mountain ranges are prone to receive more rainfall than others. Most of the basins are often rimmed by mountains. This obviously calls for some

adjustment. There are many ways to bring about this adjustment, one of them is to use the ratio of mean annual precipitation values at storm and project basin or maximum observed point precipitation of simultaneous period of record as a transposition index. An example of storm transposition is given in Annex B and Fig. 6.

3) *Seasonal adjustment* — Care should be taken that winter storms are not transposed to the summer or pre-monsoon to post-monsoon. However, this may be possible by either using the moisture adjustment or by some other rainfall parameter such as a ratio between rainfalls of two different months, and using this ratio as the transposition index.

6 RATIO OF PEAK PRECIPITATION TO STORM AVERAGE

6.1 In an isohyetal map, the intensity of precipitation diminishes in all directions from one or more peak values called storm centres. This rate of decrease depends upon many variable factors involving the type of storm, location and topography, distribution and movements of air masses and practically every other causative agency operating in a storm. The isohyetal patterns of no two storms are closely alike although many may contain similar features.

6.1.1 The ratio of the highest point rainfall depth to the average indicates the rate at which the precipitation diminishes from the peak to the edge of the storm area. Curves similar to depth-area curves may be constructed by dividing the peak depth by the average depth for a given area and plotting the ratios against the area. Such curves are useful for indicating possible reductions of average precipitation in case the storm is transposed over other basins.

7 RAINFALL FREQUENCY

The data for computing the frequency of precipitation consists of the rainfall depths for various periods of time. The unit of time selected varies with the purpose for which the frequency studies are to be used. For small areas, as used in sewer design, frequencies are needed for short period varying from 15 min to 2 h.

8 RETURN PERIOD

8.1 Estimation of Return Period

The annual extreme values of rainfall for the several years for which data are available shall be arranged in descending order so that the highest has the first rank and the lowest the last rank. The return period or the recurrence interval (T_r) when the value of the mth rank would occur or be exceeded shall be determined by the formula:

$$T_r = \frac{n+1}{m}$$

where

n = total number of values (or years) of annual rainfall, and

m = rank number.

8.1.1 The points are plotted on a logarithmic graph with T_r as abscissa and the corresponding rainfall value as the ordinate and the line of best fit is drawn. From this curve the depth of rainfall for different return periods are obtained. The extrapolation of the curve for a period not more than one and half times of the length of data available may normally be carried out.

8.2 Short Duration Curve

The rainfall of any n year return period on a given duration (t hour) is the amount of rainfall in t hour duration which will be equalled or exceeded once every n years on the average, over a long period of time. The intensities of rainfall of different durations will be required for fixing the design flood in the design of drainage structures. In order to obtain the short duration rainfall intensities for different return periods, relation between n year t hour value to n year 24 h value shall be determined. If the short duration rainfall data are available for more than 10 years, stable ratio between n year t hour to n year 24 years rainfall may be found out which can be used to determine various in year t hour values from the corresponding n year 24 year values. This may be obtained by application of the return period analysis (*see* **8.1**) to the daily rainfall.

NOTE — As rainfall data over 60 years for about 500 raingauge stations in India are available, the n year 24 h depth of rainfall can be computed for 100 years (n = 100).

8.2.1 *Limitations of the Ratio*

It is assumed that the n year 24 h rainfall ratio remains constant for all values of n which is not true. In such cases the ratio may be obtained from the enveloping curve drawn on a graph paper plotting t hour rainfall and corresponding 24 h rainfall (which covers the t hour value) from all heavy rainfall intensity records for the station. From the 24 h, t hour enveloping curve using the corresponding n year depth, the n year t hour rainfall intensity may be calculated.

8.2.2 *Ratio of n Year 1 h Rainfall to n Year 24 h Rainfall*

The hourly (clock hours) rainfall data from all past records of the stations shall be arranged in descending order of magnitude and given rank numbers 1, 2, etc. While tabulating, in order to treat the different values

choosen as independent occurrences not more than one clock hour amount in any consecutive period of 6 h shall be taken. The return period T_r may be calculated as in **8.1**. Rainfall values shall be plotted against the return periods on logarithmic paper and the line of best fit shall be drawn.

8.2.2.1 The plotting for two stations is given in Fig. 7. From this curve the 2 year 1 h rainfall amount for the station is obtained. This will be the amount of rainfall in 1 h which will be equalled or exceeded on the average once in 2 years. In the same way the 2 year 1 h rainfalls is obtained from all the stations. Next the 24 h rainfall data of the stations for the years covered by the recorded raingauge data (or for longer period) is analyzed and the 2 year 24 h rainfall obtained. The ratio (percentage) of 2 year 24 h rainfall to the 2 year 1 h rainfall shall then be found for the stations. The limitations given in **8.2.1** apply in this case also. This ratio has been found to be unstable unless the data of recording raingauges has extended to more than 10 years. In such case the ratio is obtained from an enveloping curve drawn on normal graph paper plotting t hour and corresponding 24 h rainfall using all the points for heavy rainfall. From 24 h depth, the t hour intensity of T_r year return period is calculated. The T_r year 24 h value can always be found because for most stations the 24 h rainfall data are available for more than 30 to 40 years.

9 DESIGN STORM

9.1 There are two types of storms which may be considered for design purposes. They are 'Probable Maximum Storm (PMS)' and 'Standard Project Storm (SPS)' the former being the higher of the two. With critical temporal distribution these give 'Probable Maximum Flood (PMF)' and 'Standard Project Flood (SPF)' respectively for a project basin. The basic data needed to undertake such studies regarding the two types of storms are the depth area duration tabulations of the severe historical storms in the basin under consideration. For small catchments, point rainfall data after statistical analysis may serve the purpose.

9.2 Standard Project Storm (SPS) Depth

The standard project storm is one which is reasonably capable of occurring over the basin in question. It is the heaviest rainstorm which has occurred in the region of the basin during the period of rainfall records. It may not be maximized for most critical atmospheric conditions, but it may be transposed from an adjacent region to the watershed under study after due modifications on the basis of climatological and orographic considerations. It is used where relatively some risk may be entertained and protection against the probable maximum storm is not considered essential.

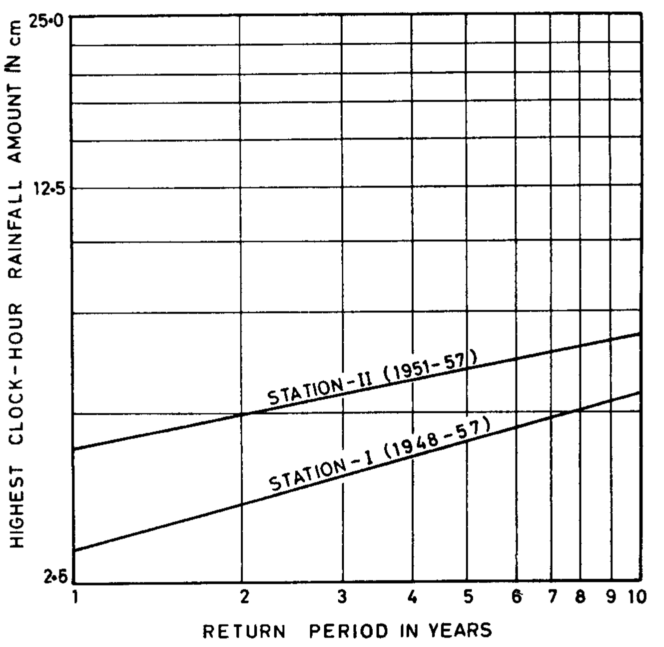

FIG. 7 FREQUENCY CURVES OF CLOCK-HOUR RAINFALL

9.3 Probable Maximum Storm (PMS) Depth

The determination of maximum probable storm involves upward adjustment of the heaviest observed rain storms in and near the catchment, for the precipitable water content appropriate to the maximum observed dew points and for maximum storm efficiency in the area. The maximum probable storm concept envisages the physical uppermost limit to storm rainfall and is used for a basin where no risk could be entertained. In this case the heaviest storm in and around the catchment is transposed and the design storm depth is calculated after maximization.

9.4 Design Storm Duration

Design storm of duration equivalent to base period of the unit hydrograph (in respect of fan shaped catchments of 5 000 km^2 and below) rounded to the next nearest value which is in multiples of 24 h and less than and equal to 72 h is considered adequate as far as design storm duration is concerned.

9.4.1 For critical storm duration required for estimating the design flood that is, for assembling design storm hyetograph elements during the storm duration equivalent to the base period (*see also* **9.4**) adjusted to next nearest value in multiples of 12 h or 72 h whichever is less shall be adopted. This procedure eliminates additional volume accruing in the design flood.

9.4.2 In respect of large catchments (where distributed models are used for designating the response of the catchments) the storm duration for causing the PMF, is to be equivalent to 2.5 times the travel time from the farthest point to the site of structure (time of concentration).

10 STORM MAXIMIZATION

10.1 Storm maximization is one of the hydrometeorological approaches to estimate maximum precipitation. Its objective is to ascertain by how much the rainfall of a particular storm be increased by consideration of maximum storm efficiency and maximum possible moisture charge. This value is the maximum probable storm (*see* **9.2**). For example, heavy precipitation occasioned by lifting of air on the windward side of a mountain might have been of even greater intensity had the storm shifted to a nearby steeper slope. A storm fed by a strong inflow of tropical air might have given more rainfall if the specific humidity of the tropical air had been higher.

10.2 Methods in Storm Maximization

10.2.1 *Maximum Moisture Index*

The first step in moisture maximization is to determine the maximum atmospheric moisture that may be expected in the region during storm. A method satisfactory for most localities is to survey a long record of surface dew point or vapour pressure measurements at several stations. All high values for each station are plotted against date and a smooth seasonal envelope drawn. Monthly/fortnightly value are then read off these graphs adjusted to a standard elevation and plotted on map. (The elevation adjustment is along moist adiabat from the mean station pressure to 1 000 millibars.) Smooth enveloping isopleths (line of equal values) are drawn on the maps and the values they indicate adopted as the index of maximum moisture for storm maximization purposes. The surface dew point should be maximum persistant dew point temperature for 12 h or maximum dew point temperature for a day recorded during days when synoptic situation is favourable for the occurrence of heavy rainstorm as similar to that in record at project catchment or in meteorological homogenous neighbourhood.

10.2.2 *Storm Moisture Index*

The second step in the moisture maximization is to obtain a measure of the moisture in the warm, moist air entering the particular storm area. This may be done by considering the persistently high dew points that may be found at several weather stations in the tropical air flowing into this storm.

10.2.2.1 The stations from which dew point data are obtained should be in the path of moist current flowing into the storm area. Keeping in view the area of particular storm for which moisture adjustment factor is to be computed, dew point data of all the stations in and around the belt of moisture influx for all the synoptic hours (that is 0830 h and 1730 h IST) of observations are to be compiled for a day prior and after the day of heavy rainstorm. From this data representative stations for the storm should be selected by proceeding upstream along the trajectory of moist air flowing into the storm centre. From the data of the representative dew points their persistent value is picked up. This will give the storm moisture index. Next step will be to obtain maximum representative 12 h persistant or one day maximum dew points temperature on record with respect to the problem catchment under investigation and find the envelope value for computing the maximum moisture index.

10.2.3 *Storm Adjustment*

The objective of storm maximization is to estimate by how much the rainfall of a particular storm would have been increased had meteorological factors which cause the storm, approached their estimated physical upper limits. These factors are:

a) The mechanical efficiency of the storm in

transforming water vapour and droplets in the atmosphere into rain, and

b) The moisture content of the rain producing air mass involved in the storm.

10.2.3.1 The precipitable moisture contents in the rain producing air mass near the storm centre may be taken to be a single valued function of the surface level dew point temperature of the air reduced to a standard pressure level of 1 000 mb.

10.2.3.2 The maximum precipitable moisture content of the same air mass is conceived to be the expected precipitable water when the surface level dew point temperature of this air mass is hypothetically made equal to the highest recorded dew point temperature in the area. The ratio of the maximum precipitable moisture content of a storm to its precipitable moisture content based on persistent dew point is known as maximization factor. The storm rainfall amounts for various areas and durations when multiplied by this factor give the corresponding maximized values of rainfall depths. In case requisite dew point data are not available, this factor should be taken as 1.10 for coastal storms and 1.25 for inland storms.

10.2.4 *Example for Calculation of Maximization Factor*

a) Relevant data used:

1)	Location of the storm	Jaipur
2)	Duration of the storm	September 17 to 19, 1928
3)	Representative persistent dew point	21.1°C (say)
4)	Inflow barrier for the storm area	366 m (say)
5)	Maximum dew point on record with reference to basin reduced to 1 000 mb or sea level	23.9°C
6)	Inflow barrier to the basin corresponding to maximum dew point 23.9°C	793 m
7)	Location of the basin	—

b) Computation of precipitable water (for storm) (*see* Fig. 8), or Table 1:

1)	1 000 mb or sea level dew point	21.1°C
2)	Inflow-barrier	366 m
3)	Precipitable water (1 000 mb to 200 mb)	5.84 cm
4)	Precipitable water (1 000 mb to 366 mb)	0.51 cm
5)	Precipitable water (366 mb to 200 mb) that is d_1	5.33 cm

c) Computation of precipitable water (for project basin) (*see* Fig. 8):

1)	1 000 mb or sea level dew point	23.9°C
2)	Inflow barrier	793 m
3)	Precipitable water (1 000 mb to 200 mb)	7.37 cm
4)	Precipitable water (1 000 mb to 793 mb)	1.52 cm
5)	Precipitable water (793 mb to 200 mb) that is d_2	5.85 cm

d) Moisture maximization factor taking into account orography

$$\frac{\text{Adjusted precipitable water for project basin } (d_2)}{\text{Adjusted precipitable water for observed storm } (d_1)}$$

$$= \frac{5.85}{5.33} = 1.1$$

The highest persistent dew point for some specified time interval is the value equalled or exceeded at all observations during the period of rainstrom. Let us consider the following series of dew points observed at 6 h interval:

Time UTC	00	06	12	18	00	06	12	18
Dew Point,°C	19.0	19.0	20.1	21.1	23.2	21.1	17.0	18.0

The highest persistent 12 h dew point for the above example is 21.1 which is obtained from the period 18 to 06 h. However, if the air temperature had dropped below 20.1°C during the period 00 to 06 then the highest persisting 12 h 1 000 mb dew point would be 20.1°C which is obtained from the period 12 to 00 h.

10.3 Time Adjustment of Storm Rainfall

10.3.1 *Clock-Hour Correction*

The maximum 1 day rainfall obtained from the analysis of daily data recorded at fixed time intervals would be less than the maximum falls for unrestricted period of 24 h. This is because the maximum 24 h rainfall would seldom coincide with observational day's rainfall. The rainfall depth to be used in the estimation of design flood should be for durations not fixed by observation times. On an average maximum 24 h rainfall is found to be 1.15 times the corresponding daily rainfall limited to an excess value of 50 mm. This factor should, therefore, be applied to convert 1 day design storm depth to corresponding 24 h depth. However this correction should be applied only to catchment areas up to 5 000 km^2. For larger areas no such correction is warranted. Similarly for higher durations no correction

Table 1 Precipitable Water (mm) Between 1 000 mb Surface and Indicated Height (m) Above that Surface in a Saturated Pseudo-Adiabatic Atmosphere as a Function of the 1 000 mb Dew Point (°C)

[*Clause* 10.2.4 (b)]

Height (m)	1 000 mb Temperature (°C)																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
200	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6
400	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	7	7	8	8	9	9	10	10	11	12
600	3	3	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	9	10	10	11	11	12	13	14	15	15	16	17
800	3	3	4	4	4	5	5	5	6	6	7	7	8	8	9	9	10	10	11	12	13	13	14	15	16	17	18	19	20	21	2
1 000	4	4	4	5	5	6	6	6	7	7	8	9	9	10	10	11	12	13	13	14	15	16	17	18	20	21	22	23	25	26	24
1 200	4	5	5	6	6	7	7	8	8	9	9	10	11	11	12	13	14	15	16	17	18	19	20	21	25	24	26	27	29	31	32
1 400	5	5	6	6	7	7	8	8	9	10	10	11	12	13	14	15	16	17	18	19	20	22	23	24	26	28	29	31	33	35	37
1 600	5	6	6	7	7	8	9	9	10	11	11	12	13	14	15	18	17	19	20	21	23	24	25	27	29	31	33	35	37	39	41
1 800	6	6	7	7	8	9	9	10	11	12	12	13	14	15	17	18	19	20	22	23	25	26	28	30	32	34	36	39	41	43	46
2 000	6	7	7	8	9	9	10	11	11	12	13	14	16	17	18	19	21	22	24	25	27	29	31	33	35	37	39	42	44	47	50
2 200	7	7	8	8	9	10	10	11	12	13	14	15	16	18	19	20	22	24	25	27	29	31	33	35	37	40	42	45	48	51	54
2 400	7	8	8	9	9	10	11	12	13	14	15	16	17	19	20	22	23	25	27	29	31	33	35	37	40	43	45	48	51	54	57
2 600	7	8	8	9	10	11	11	12	13	14	16	17	18	20	21	23	24	26	28	30	32	35	37	40	42	45	48	51	55	58	61
2 800	7	8	9	9	10	11	12	13	14	15	16	18	19	21	22	24	26	27	30	32	34	35	39	42	45	48	51	54	58	61	65
3 000	8	8	9	10	10	11	12	13	14	15	17	18	20	21	23	25	27	29	31	33	35	38	41	44	47	50	53	57	61	64	68
3 200	8	8	9	10	11	12	13	14	15	16	17	19	20	22	24	26	28	30	32	34	37	40	42	45	49	52	56	59	63	67	71
3 400	7	8	9	10	11	12	13	14	15	16	18	19	21	23	24	26	29	31	33	36	38	41	44	47	51	54	58	62	66	70	74
3 600	8	9	9	10	11	12	13	14	15	17	18	20	22	23	25	27	29	32	34	37	39	42	45	49	52	56	60	64	68	75	77
3 800	8	9	10	10	11	12	13	14	16	17	19	20	22	24	26	28	30	32	35	38	41	44	47	50	54	58	62	66	70	75	80
4 000	8	9	10	11	11	12	14	15	16	17	19	21	22	24	26	28	31	33	36	39	42	45	48	52	56	60	64	68	73	80	83
4 200	8	9	10	11	12	13	14	15	16	18	19	21	23	25	27	29	31	34	37	40	43	46	49	53	57	61	65	70	75	82	85
4 400	8	9	10	11	12	13	14	15	16	18	20	21	23	25	27	29	32	34	37	40	44	47	51	54	58	63	67	72	77	84	87
4 600	8	9	10	11	12	13	14	15	17	18	20	22	24	25	28	30	32	35	38	41	44	48	52	56	60	64	69	74	79	86	90
4 800	8	9	10	11	12	13	14	15	17	18	20	22	24	26	28	30	33	36	39	42	45	49	53	57	61	65	70	75	81	88	92
5 000	8	9	10	11	12	13	14	16	17	19	20	22	24	26	28	31	33	36	39	42	46	50	54	58	62	67	72	77	82	90	94
5 200	8	9	10	11	12	13	14	16	17	19	20	22	24	26	29	31	34	37	40	43	47	50	54	59	63	68	73	78	84	92	96
5 400	8	9	10	11	12	13	14	16	17	19	20	22	24	26	29	31	34	37	40	44	47	51	55	60	64	69	74	80	85	93	98
5 600	8	9	10	11	12	13	14	16	17	19	21	22	24	27	29	32	35	38	41	44	48	52	56	60	65	70	76	81	87	95	100
5 800	8	9	10	11	12	13	14	16	17	19	21	22	25	27	29	32	35	38	41	45	48	52	57	61	66	71	77	82	88	95	101
6 000	8	9	10	11	12	13	15	16	17	19	21	23	25	27	30	32	35	38	42	45	49	53	57	62	67	72	78	84	90	98	103
6 200	8	9	10	11	12	13	15	16	17	19	21	23	25	27	30	32	35	38	42	45	49	54	58	63	68	73	79	85	91	99	104
6 400	8	9	10	11	12	13	15	16	18	19	21	23	25	27	30	33	35	39	42	46	50	54	58	63	68	74	80	86	92	100	105
6 600	8	9	10	11	12	13	15	16	18	19	21	23	25	27	30	33	36	39	42	46	50	54	59	64	69	74	80	87	93	101	107
6 800	8	9	10	11	12	13	15	16	18	19	21	23	25	27	30	33	36	39	42	46	50	55	60	65	70	75	81	87	94	102	108
7 000	8	9	10	11	12	14	15	16	18	19	21	23	25	28	30	33	36	39	43	46	51	55	60	65	70	76	82	88	95	103	110
7 200	8	9	10	11	12	14	15	16	18	19	21	23	25	28	30	33	36	39	43	47	51	55	60	65	71	76	82	89	96	104	111
7 400	8	9	10	11	12	14	15	16	18	19	21	23	25	28	30	33	36	39	43	47	51	56	61	66	71	77	83	90	97	105	112
7 600	8	9	10	11	12	14	15	16	18	19	21	23	25	28	30	33	36	39	43	47	51	56	61	66	72	77	83	90	98	106	113
7 800	8	9	10	11	12	14	15	16	18	19	21	23	25	28	30	33	36	39	43	47	51	56	61	66	72	78	84	91	98	107	114
8 000	8	9	10	11	12	14	15	16	18	19	21	23	26	28	30	33	36	40	43	47	52	56	61	67	72	78	85	92	99	108	115
8 200	8	9	10	11	12	14	15	16	18	19	21	23	26	28	30	33	36	40	43	47	52	57	62	67	73	78	85	92	100	108	115
8 400	8	9	10	11	12	14	15	16	18	19	21	23	26	28	30	33	36	40	43	47	52	57	62	67	73	79	85	92	100	109	116
8 600	8	9	10	11	12	14	15	16	18	19	21	23	26	28	30	33	36	40	43	47	52	57	62	68	73	79	86	93	101	109	117
8 800	8	9	10	11	12	14	15	16	18	19	21	23	26	28	30	33	36	40	43	47	52	57	62	68	73	79	86	93	101	110	118
9 000	8	9	10	11	12	14	15	16	18	19	21	23	26	28	31	33	36	40	43	47	52	57	62	68	74	80	86	94	102	110	118
9 200	8	9	10	11	12	14	15	16	18	19	21	23	26	28	31	33	36	40	43	48	52	57	62	68	74	80	87	94	102	110	119
9 400						14	15	16	18	19	21	23	26	28	31	33	36	40	44	48	52	57	62	68	74	80	87	94	102	111	119

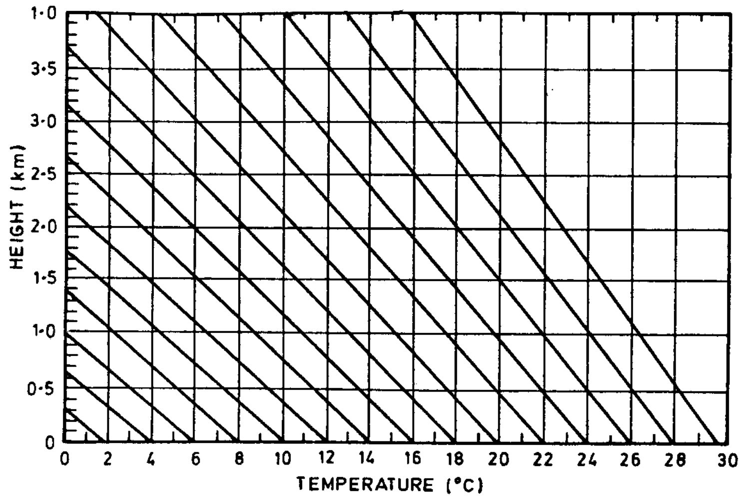

FIG. 8 PSEUDO-ADIABATIC DIAGRAM FOR DEW POINT REDUCTION TO 1 000 hPa AT HEIGHT ZERO

is required as the maximum 48 h rainfall almost equals maximum 2 day rainfall.

Where autographic records are available 1 day rainfall should be adjusted according to maximum 24 h observed rainfall.

10.3.2 *Temporal Distribution of Storm Rainfall*

When applying storm depth rainfall to determine the flood hydrograph, it is necessary to specify how the rainfalls with time. Such rainfall sequences are called mass curves. Observed mass curves show a variety of hourly sequences. From the hourly rainfall data of S.R.R.G.'s, hourly catchment average rainfall data can be computed chronologically. From these data maximum rainfall depths for consecutive duration of 1, 2, 3 h are found and plotted against duration. From the smooth envelope curve incremental rainfall depths can be found and converted to corresponding percentages of 24 h, 48 h or 72 h depth as the case may be. In case data of sufficient number of recording raingauge are not available for estimation of hourly area rainfall point rainfall depths of 5-6 individual raingauge stations in the same meteorological homogenous region each having recorded 200-250 mm rainfall in any 24 h may be used. The accumulated depths for varying duration at individual stations can be plotted as the same graph and a single average curve may be drawn. Depths for various duration read from this curve are then converted to percentage depths of 12, 24 h, etc. Storm depth are then apportioned in proportion to these percentages for applying to the catchment to estimate design flood. An example of finding temporal distribution is given in Annex C.

ANNEX A

(*Clause* 5.2.2.2)

COMPUTATIONAL SHEETS PERTAINING TO A TYPICAL CATCHMENT

Date of storm : 28 July 1965

Isohyetal Range From cm	To cm	*Mean Rain-fall* cm	*Area as Plani-Metered* cm^2	*Area* km^2	*Accumulated Area* km^2	*Volume (col 3 × col 5)* cm × km^2	*Accumulated Volume* cm × km^2	*Average Rainfall Depth (col 8/ col 6)* cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
60	67.1	63.5	0.83	83	83	5 271	5 271	63.5
50	60	55.0	1.48	148	231	8 140	13 411	58.1
40	50	45.0	5.09	509	740	22 905	36 316	49.1
30	40	35.0	5.87	587	1 327	20 545	58 861	42.9
30	30.9	30.5	1.29	129	1 456	3 935	60 796	41.8
25	30	27.5	10.58	1 058	2 514	29 095	89 891	35.8
20	25	22.5	10.19	1 019	3 533	22 927	112 818	31.9
15	20	17.5	12.06	1 206	4 739	21 105	133 923	28.3
10	15	12.5	19.22	1 922	6 661	24 025	157 948	23.7
5	10	7.5	17.41	1 741	8 402	13 057	171 005	20.4
2	5	3.5	22.45	2 245	10 647	7 857	178 862	16.8
0	2	1.0	244.39	2 443	35 086	24 439	203 301	5.8
70	79.8	74.9	6.06	606	606	45 389	45 389	74.9
60	70	65.0	6.45	645	1 251	41 925	87 314	69.8
50	60	55.0	10.71	1 071	2 322	58 905	146 219	63.0
40	50	45.0	10.06	1 006	3 328	45 270	1 901 489	57.5
30	40	35.0	11.29	1 129	4 457	39 515	231 004	51.8
20	30	25.0	20.96	2 096	6 553	52 400	283 404	43.2
10	20	15.0	21.93	2 193	8 746	32 895	316 299	36.2
5	10	7.5	34.44	3 444	12 190	25 380	341 679	28.1
2	5	3.5	92.23	9 223	21 413	32 281	373 960	17.5
0	2	1.0	136.74	1 367	35 087	13 674	387 634	11.1
80	84	82.0	5.22	522	522	42 804	42 804	82.00
60	80	70.0	17.41	1 741	2 263	121 870	164 674	72.8
40	60	50.0	25.03	2 503	4 766	125 150	289 824	60.8
20	40	30.0	35.60	3 560	8 326	106 800	496 624	47.6
10	20	15.0	38.05	3 805	12 131	57 075	453 699	37.4
5	10	7.5	56.50	5 650	17 781	42 375	496 074	27.9
2	5	3.5	65.47	6 547	24 328	22 915	518 989	21.3
0	2	1.0	107.59	10 759	35 087	10 759	529 748	15.1

ANNEX B

[*Clause* 5.3.2(e)]

TABULATION SHEET OF A TYPICAL CATCHMENT FOR STORM TRANSPORTATION

Date of Storm: 26-27 July 1913 (*see* Fig. 6)

Isohyetal Range		*Mean Rainfall*	*Area as Plani-Metered*	*Area*	*Accumulated Area*	*Volume (col 3 × col 5)*	*Accumulated Volume*	*Average Rainfall Depth (col 8/col 6)*
From	To							
cm	cm	cm	cm^2	km^2	km^2	cm × km^2	cm × km^2	cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
60	66.3	63.1	3.73	374	374	23 599	23 599	63.1
50	60	55.0	7.03	703	1 077	38 665	62 264	57.8
40	50	45.0	13.67	1 367	2 438	61 515	123 779	50.8
35	40	37.5	25.80	2 580	5 018	96 750	220 529	43.9
30	35	32.5	27.41	2 741	7 759	89 083	309 612	39.9
25	30	27.5	45.67	4 567	12 326	125 593	435 205	35.3
20	25	22.5	60.63	6 063	18 389	136 417	571 622	31.1
15	20	17.5	24.83	2 483	20 872	43 453	615 075	29.5
10	15	12.5	11.55	1 155	22 027	14 437	629 512	28.6
5	10	7.5	10.90	1 090	23 117	8 175	637 687	27.6
2	5	3.5	0.97	97	23 214	339	638 026	27.5

ANNEX C

(*Clause* 10.3.2)

TEMPORAL DISTRIBUTION COMPUTATION

Station: Jaipur

Maximum Depth (24h): 375.5 mm
Storm : 17-19 July 1981

Date/ Hour	*Observed Depth* mm	*Hours*	*Cumulative Depth* mm	*Envelope Depth* mm	*Percent of 24 h Depth* mm	*Percent of 12 h Depth* mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)
18.07.81						
12	13.5	1		80	21	25
13	8.5	2		140	37	44
14	7	3		186	49	58
15	3	4		220	59	69
16	5	5		246	65	77
17	3.2	6		262	70	82
18	2	7		276	73	86
19	3.8	8		288	77	90
20	5	9		298	79	93
21	9.5	10		307	82	96
22	17.2	11		314	84	98
23	20.6	12	80	321	85	100
24	0.1	13		328	87	
19.07.81	2	14		335	89	
2	0.5	15		342	91	
3	3.2	16		348	93	
4	4.4	17		352	94	
5	7	18		357	95	
6	13.5	19		360	96	
7	43	20		364	97	
8	56.5	21		368	98	
9	30	22		371	99	
10	80	23		374	99	
11	37	24		376	100	

ANNEX D

(Foreword)

COMMITTEE COMPOSITION

Ground Water and Related Investigations Sectional Committee, WRD 3

Organisation	*Representative(s)*
Central Ground Water Board, New Delhi	Shri D. K. Chadha (***Chairman***)
Central Electricity Authority, New Delhi	Shri Major Singh Shri S. B. Atri (*Alternate*)
Central Ground Water Board, New Delhi	Dr A. N. Bhowmick Shri Santosh Kumar Sharma (*Alternate*)
Central Pollution Control Board, Delhi	Shri T. Venugopal Shri Mita Sharma (*Alternate*)
Central Soil and Material Research Station, New Delhi	Director Shri N. K. Verma (*Alternate*)
Central Soil Salinity Research Institute, Karnal	Dr S. K. Gupta
Central Water and Power Research Station, Pune	Dr N. Ghosh Shri R. S. Ramteka (*Alternate*)
Central Water Commission, New Delhi	Chief Engineer Superintending Engineer (*Alternate*)
Centre for Water Resources Development and Management, Kerala	Head (Ground Water Division) Dr E. J. James (*Alternate*)
Geological Survey of India, Lucknow	Shri S. Kumar Shri Y. Deva (*Alternate*)
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